Volume 42 FEBRUARY, 1956 Number 2

Lubrication

A Technical Publication Devoted to the Selection and Use of Lubricants

This Issue

THE
HYDRA-MATIC
1939 THRU 1956

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Vol. XLII February, 1956 No. 2

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The Hydra-Matic, 1939 Thru 1956

INTRODUCTION

FIRST INTRODUCED in the 1939 Oldsmobile[1], the Hydra-Matic was the first fully-automatic passenger car transmission to be placed in quantity production. More than seven million of the passenger car type alone have been manufactured[2] to date. With its experience accumulated during seventeen years and probably billions of vehicle miles coupled with the many millions of engineering man hours that had been contributed by its manufacturer and by the using car manufacturers, the Hydra-Matic is undoubtedly the most highly developed mechanism of its type. Literally thousands of improvements have been made and at least 23 different Hydra-Matic models have been in production simultaneously.

Although originally intended for passenger cars, the Hydra-Matic's success in that field and its considerable adaptability has encouraged its trial and further success in such other vehicles as the light (M-5) military tank, military personnel carriers and medium trucks, motor buses, light door-to-door delivery trucks and (most recently) in heavy over-the-road long distance tractor trucks. By virtue of the Hydra-Matic's pioneering example and rapidly increasing popularity, it can also justly claim at least indirect credit for the intensive development and heavy production during the last seven years of seven other quite-different competitive automatic transmissions.

Finally the Hydra-Matic is directly responsible for the development of Automatic Transmission Fluid Type A, the most widely distributed and the most complex petroleum material available to the American public.

SCOPE

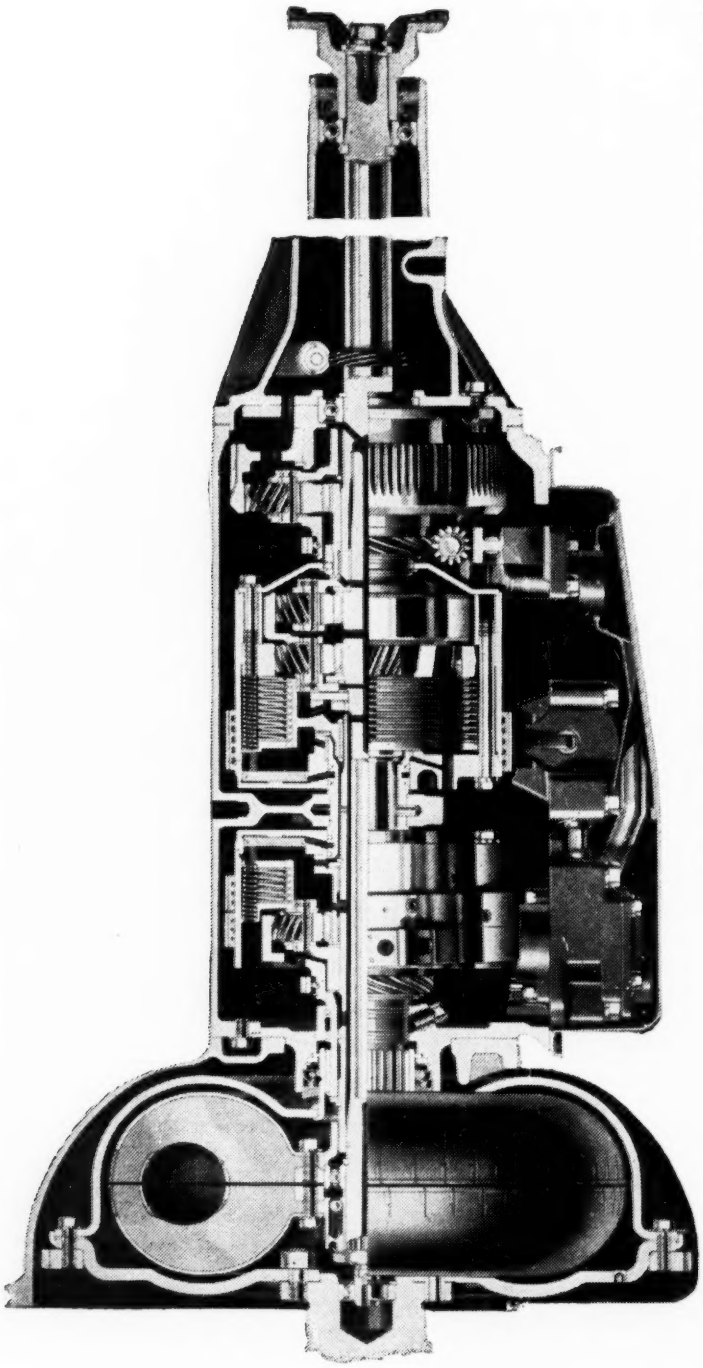
Starting with the earliest Hydra-Matic this article will attempt (1) a concise description of its major components, general operation and the principal developments that have occurred during its sixteen-year history through the 1955 model, (2) a description of operating methods of the 1956 model which differs importantly from its predecessors and (3) a description and operation of the Twin Hydra-Matic truck transmission.

HYDRA-MATIC, 1939 THRU 1955

Figure 1 presents a partial cross-section of an early Hydra-Matic which accurately shows its parts and will be used to describe the operation and development of its major components up through the 1955 model. Figure 2 is a corresponding but schematic drawing of the early transmission which is more readily understood.

From these, one could deduce that this Hydra-Matic was a highly ingenious fully-automatic hydraulically-controlled mechanical or "stepped"

[1]Then in 1941 Cadillac; 1948 Pontiac; 1949 Nash, Kaiser, light General Motors bus; 1950 Hudson, Lincoln.
[2]By Detroit Transmission Division, GMC.



Cadillac Motor Car Div., GMC

Figure 1 — 1941 Hydra-Matic, Cross Section.

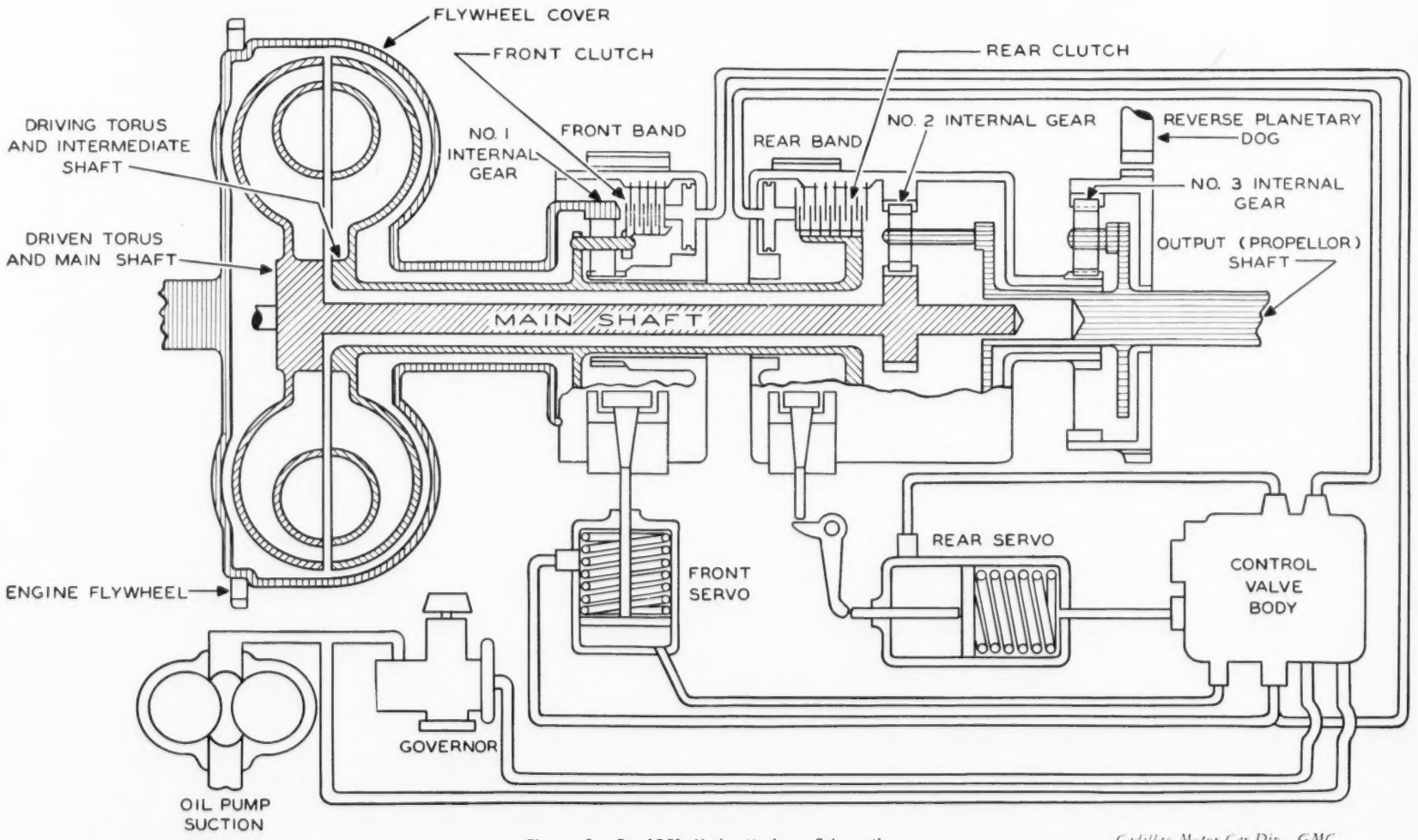
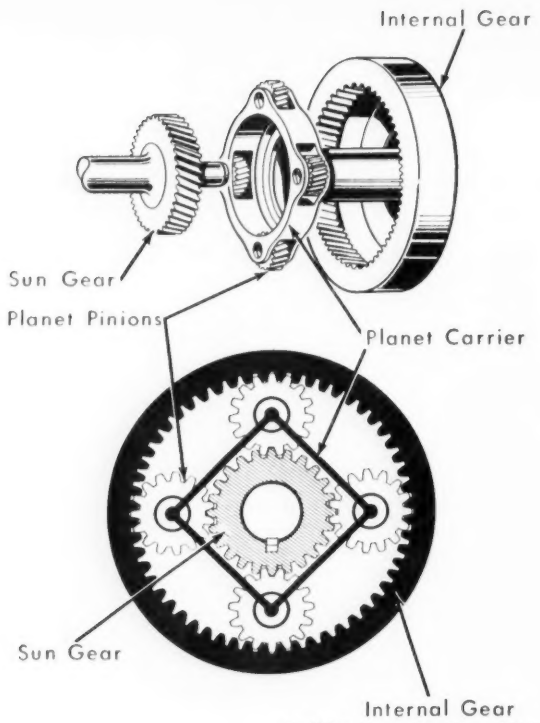


Figure 2 — Pre-1951 Hydra-Matics — Schematic.

Cadillac Motor Car Div., GMC



Cadillac Motor Car Div., GMC

Figure 3 — Planetary Gear.

transmission employing three planetary gear sets, a fluid coupling and the necessary manual and automatic hydraulic controls. With these mechanisms it provides full automatic shifting up and down through four forward speed ratios, a neutral position and one reverse speed ratio. Following are descriptions of the major elements.

Planetary Gear Set

The lower portion of Figure 3 schematically illustrates a simple planetary gear set as consisting of three major assemblies: (1) a central "sun" gear; (2) a "planet carrier" carrying one or more (in this instance four) "planet" gears, each mounted and free to rotate around its own axis while the planet carrier may rotate on the same axis as the sun gear; (3) the outermost "internal gear" — so called beause of its internal teeth — which may also rotate around the same common central axis as the sun gear and planet carrier. The planet gears are *always* meshed with both the sun gear and internal gear and no "shifting" of gears occurs. The remarkable capabilities of such a relatively simple mechanism are described in the following seven sub paragraphs.

1. *Forward Drive, Major Torque Multiplication.* From study of Figure 3 it will be seen that if the internal gear is held *stationary* while the sun gear is *driven* clockwise, the planets are rotated counter-clockwise around their own axes. Since they are also meshed with the stationary internal gear, they must "walk" clockwise around the sun gear and thereby rotate their planet carrier in a clockwise direction at much lower rotational speed than the sun gear and with correspondingly higher torque. The second planetary of all Hydra-Matics including the 1956 contributes torque multiplication in this manner.

   As an aside, the common overdrive mechanism used with some manual transmissions is also a planetary gear that functions in this same manner. However such an overdrive is neither necessary nor desirable in the Hydra-Matic.

2. *Forward Drive, Minor Torque Multiplication.* If the sun gear is held stationary while the internal gear is driven clockwise, a similar action but of lesser effect occurs. In this case the internal gear drives the planets clockwise and forces them to "walk" clockwise around the stationary sun gear, carrying their planet carrier clockwise at a lower speed with higher torque than the internal gear. The first planetary unit of the 1956 Hydra-Matic can function in this manner.

3. *Direct Drive Coupling.* If *any two* of the three major assemblies of a planetary gear set are locked together in some manner, the entire set is locked and rotates as a solid unit or coupling which merely transmits speed and torque without changing either. In pre-1956 Hydra-Matics, the first planetary was locked up by engaging its clutch thus connecting its sun gear and planet carrier; the second planetary was locked by connecting its sun gear and internal gear through its clutch and the fluid coupling. Both the first and second planetary units of the 1956 Hydra-Matic accomplish direct drive by having their internal and sun gears rotate in the same direction and at the same speed, thus in effect locking them together.

4. *Neutral or Idling Position.* If power is applied to any one of the three planetary gear major assemblies, *and neither of the other two is restrained,* no torque is transmitted and the elements merely rotate or "idle" in their neutral position. For example in pre-1956 Hydra-Matics the internal gear of the first planetary gear set was connected to and always driven by the engine, but if the sun gear was not restrained, no torque was transmitted to the planet carrier output, and the gear set was therefore in neutral. Furthermore in pre-1956 Hydra-Matics both the first and second planetary gear sets could be placed in neutral for Neutral position. Due to different construction of the first planetary in

TABLE I
Planetary Useage, Pre-1956 Hydra-Matics

Gear Range	*#1 (Front) Planetary*	*#2 (Center) Planetary*	*#3 (Rear & Reverse) Planetary*	*Total Reduction Ratio*
Neutral	Neutral	Neutral	Neutral	0
First (low)	Reduction	Reduction	Neutral	3.82
Second	Direct Drive	Reduction	Neutral	2.63
Third	Reduction	Direct Drive	Neutral	1.45
Fourth (high)	Direct Drive	Direct Drive	Neutral	1.00 (high)
Reverse	Reduction, reverse rotation	Neutral	Reduction	4.3

1956 Hydra-Matics (which will be described later) the first planetary can no longer be placed in the passive neutral position and the second planetary takes over entire responsibility for the neutral phase.

5. *Reverse.* If power is applied to the sun gear in a clockwise direction and the planetary carrier is restrained, then the planets must rotate counterclockwise and *drive the internal gear in a counterclockwise or reverse direction from the input sun gear.* In all Hydra-Matics including the 1956 model, the reversal of drive is accomplished in this manner within the second planetary while additional torque multiplication without change in direction occurs in the third, or reverse planetary. The anomaly is apparent — the second normally forward-drive planetary now acts as a *reverse* while the third *reverse* planetary doesn't reverse at all. As an aside however, this situation illustrates the highly ingenious interplay of mechanisms that is characteristic of the Hydra-Matic and the consequent difficulty of adequately describing it.

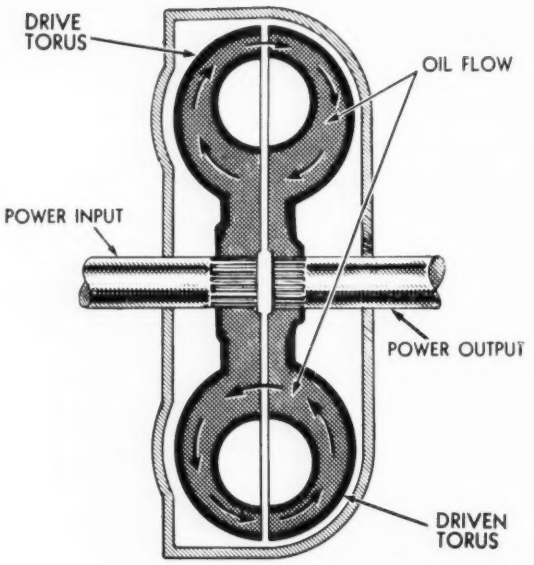
6. In summary, all pre-1956 car Hydra-Matics contain three planetary gear sets *of different ratios* and use them singly or in combination to obtain four forward speeds[3], neutral, and reverse as indicated in Table I.
The reader may note from the table that if the first two planetaries used the same reduction ratio, only three forward speeds would be possible.

7. *Planetary Gear Set "Pros and Cons".* From the foregoing descriptions it should be obvious that the remarkable versatility of the planetary gear set is the principal reason for its wide useage in automatic transmissions but there are also many others. For example the planetary gear is extremely compact and readily adaptable by the designer because of the coaxial relationship of its three assemblies. Since its gearing is always in mesh, no noisy and damaging gear shifts of the conventional type are needed. For similar reasons it is extremely sturdy and can handle much more torque for its size and weight than conventional open gearing. In this connection a close reexamination of the second planetary in Figure 1 will show that for design and strength reasons it was thought necessary in that early model to use *two* planetary gear sets in combination, each having *three* planets. Later designs accomplished the same purpose with a single planetary gear set containing four planets which distributed and shared the torque load.

The fact that the torque multiplication ratios of a planetary gear set are fixed by its design and are constant in operation is both a large advantage and a moderate handicap. When used in an automotive transmission, such a fixed-ratio gear can give very high power transmission efficiency (with more miles per gallon!) but the limited useable operating range of any one ratio necessitates the use of several. As seen however each planetary gear set can furnish two or three different ratios, therefore its inherent versatility serves to overcome its own handicap.

The fact that there is no slippage in mechanical gearing is therefore very welcome from an efficiency standpoint, but the very absence of slippage or "cushioning" of some sort makes the problem of automatically and smoothly changing from one fixed ratio to another not easily solved. In fact one early semi-automatic transmission which employed two simple planetary gears in concert and was otherwise strikingly suggestive

[3]One exception to this was Oldsmobile's "Whirlaway" version which normally started in second gear and therefore normally used only its three higher speeds.



Pontiac Motor Div., GMC

Figure 4 — Fluid Coupling — Schematic.

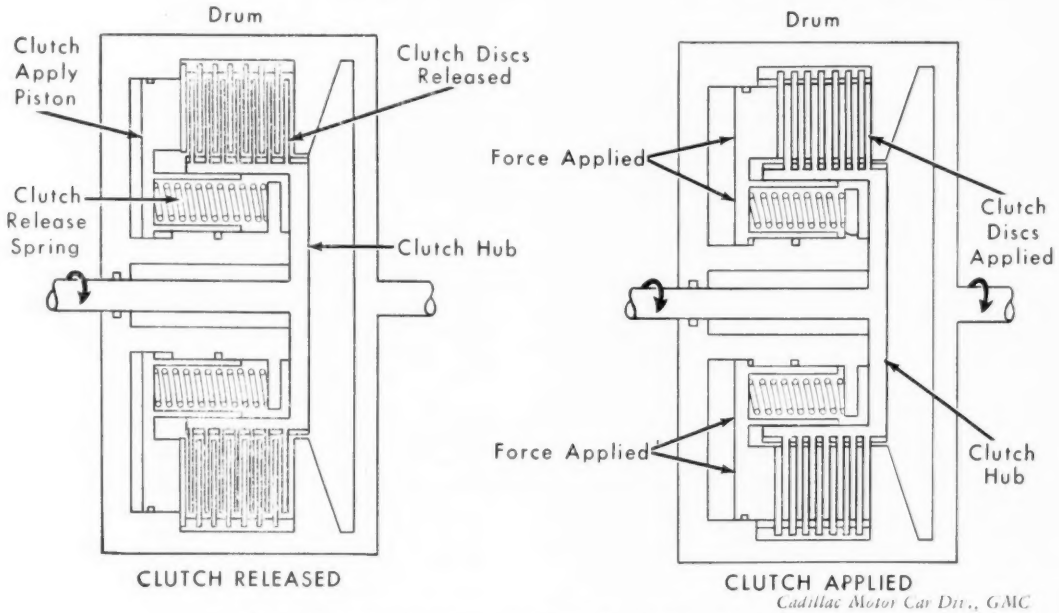
of the Hydra-Matic was abandoned quickly by its proponent, largely because smooth shifting and quiet operation could not be obtained.

The search for a cushioning element led to a comparatively unknown hydraulic mechanism named "fluid coupling".

Fluid Coupling

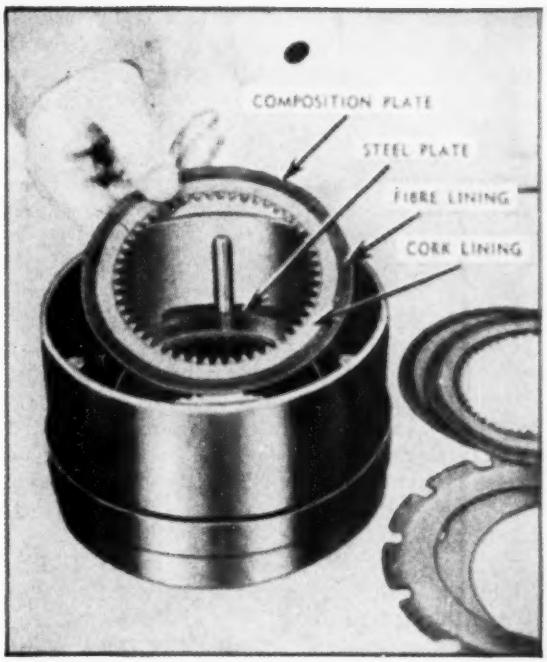
Figure 4 schematically illustrates the fluid coupling which has some outstanding characteristics that make it a major partner to planetary gear sets and is used as such in all Hydra-Matics. Each "torus" of the pair in a fluid coupling resembles a half-grapefruit with the pulp removed, and revolves on a separate but coaxial shaft within an oil-tight casing. If the case is now entirely filled with a light oil and one torus is rotated, the other will "follow" it by rotating in the same direction at very close to the same speed. Even if the second torus is prevented from rotating, it will develop and transmit a static torque that is exactly equal to the torque exerted on the first torus. Thus input and output torque are always equal, regardless of which torus may be driving, the direction of rotation, or any positive difference between input and output speeds. The coupling is a hydrodynamic ("fluid in motion") device, and must contain a fluid to absorb and transmit kinetic energy by circulation from the input to the output torus where it is reconverted to torque and power. See arrows in Figure 4 for fluid circulation path. If there is no fluid or no circulation in a fluid coupling then no torque will be transmitted, an application that is put to good use in the controlled or "dumping coupling" of the front planetary unit in the 1956 Hydra-Matic. In effect the fluid coupling is a special type of clutch which has no friction plates and can therefore be "slipped" almost indefinitely without damaging itself. (In applications where lengthy slipping is anticipated, the coupling casing may not be able to radiate enough of the resultant heat, and an external fluid cooler or heat exchanger is provided.)

Because of its fluid coupling, and fully automatic shifting, the Hydra-Matic pioneered the elimination of the conventional foot-operated clutch and its



Cadillac Motor Car Div., GMC

Figure 5 — Hydraulically-operated multi-disc clutch — Schematic.



Oldsmobile Div., GMC

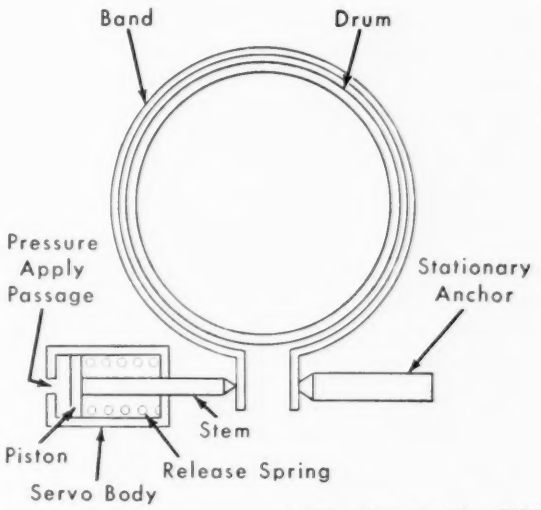
Figure 6 — Hydra-Matic Clutch Plates and Drum.

obtrusive foot pedal. Though as Figure 1 illustrates, the Hydra-Matic coupling is physically at the front or engine end of the transmission, a careful reexamination of Figure 2 will show that it actually exerts its many beneficial effects on and between the first and second planetary gear sets. For this same reason and unlike all other transmissions, the Hydra-Matic's fluid coupling rotates at considerably less than engine speed, therefore at a correctly adjusted engine idling speed, the coupling does not transmit enough torque to cause the car to "creep" forward before its driver intends. Again because of the coupling's unusual position and during third and fourth (high) gear operation, the Hydra-Matic operates on the famous "split torque" principle since part of the torque is transmitted mechanically through the planetaries and part hydraulically through the coupling.

Multi-Disc Clutch

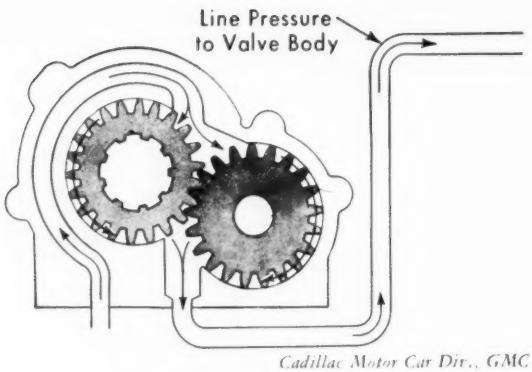
Multi-disc clutches are widely used in all automatic transmissions to lock up planetary gears and to control other mechanisms. All pre-1956 Hydra-Matics use two, and the very similar cone-type reverse planetary clutch might be counted as a third.

Figure 5 schematically presents such a clutch of the "wet" (oil-immersed) type which is engaged or applied by hydraulic pressure and released by spring action. The clutch consists of a set of one or more (seven in Fig. 5) driving plates which are internally splined to and driven by the clutch hub. A second set of driven plates are splined or notched on their periphery to engage and drive the clutch drum. Both plate sets have limited freedom to move axially, and are kept separated in their normal release position by spring action. When clutch engagement is desired, oil under pressure is applied to the clutch apply piston, the plates are forced into close contact and the resulting friction rapidly reduces any speed difference between them to zero when they adhere and the entire mechanism then rotates as a single unit. The earliest Hydra-Matic clutch employed six small hydraulic apply pistons which were superseded in 1946 and subsequent models by the simpler and more effective single annular piston illustrated in Figure 5. Originally the clutch driving plates were made of bronze with the driven plates of steel. While rugged and long-lasting, the flat thick bronze plates had a tendency to engage roughly and be slightly noisy during the critical "slip-stick" phase of engagement. All subsequent passenger car Hydra-Matics have employed special thin spring-steel driving plates faced with concentric rings of cork composition and Krafelt fibre cemented on them to promote smooth engagement. For the same reason these composition plates are also deliberately "waved" with six alternate high and low sections from 0.010" to 0.020" deep. Figure 6 illustrates both the composition and steel plates and the method of alternately assembling them into a Hydra-Matic drum to form a "stack". The number of plates in such a stack together with the amount and rate of hydraulic apply and release pressures can all be varied to change clutch torque capacity and engagement characteristics.



Cadillac Motor Car Div., GMC

Figure 7 — Hydraulic Servo — Schematic.



Cadillac Motor Car Div., GMC

Figure 8 — Oil Pump, external twin gear type — Schematic.

Brake or Overrun Band

Where it is desired to stop a rotating drum and to hold it immovable, a contracting brake band like that schematically illustrated in Figure 7 has been widely used. The flexible steel brake band is lined with a heat-resistant frictional material, wrapped one or more times around its drum and with one end anchored to the stationary transmission case, the other is "pinched in" by some mechanism such as the hydraulic servo so as to grasp and hold the drum. All Hydra-Matics up to the 1956 model have used two such bands to control the first planetary's sun gear and second planetary's internal gear.

Servo

Also illustrated in Figure 7 is a hydraulic "servo" which is simply a method of converting hydraulic pressure into a mechanical force by means of a cylinder and piston. The type shown which is applied hydraulically and released by spring pressure has been used to hold the sun gear of the first planetary in all pre-1956 Hydra-Matics. A second type which was applied by spring pressure and released by hydraulic pressure was similarly used with the second or "rear" planetary. In both types either or both the application and release actions may be hastened, reinforced or delayed by springs, hydraulic pressure and control orifices, therefore the actual servo mechanism is more complex than that illustrated.

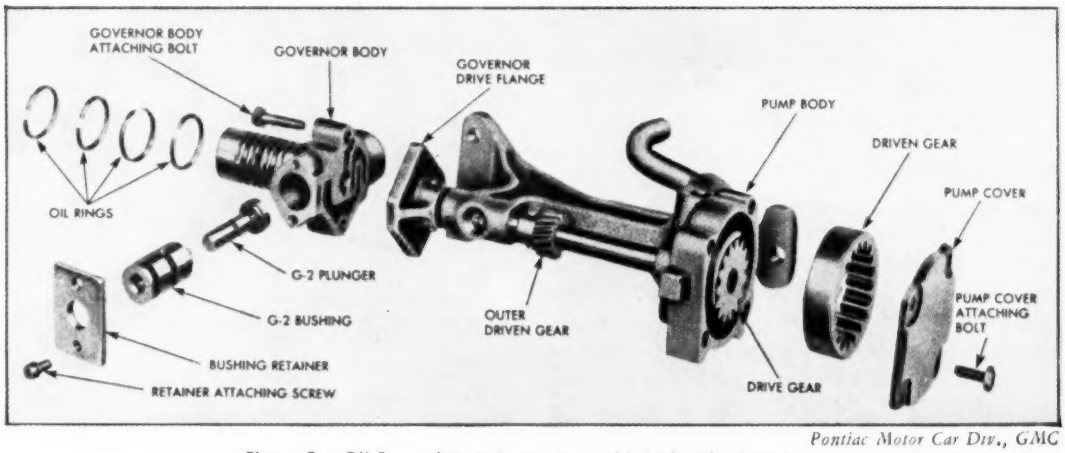
Oil Pumps

In all Hydra-Matics, oil under pressure is used not only to lubricate, cool, and transmit power but to release or apply the subsidiary mechanisms in their proper sequence and at the correct times. To provide sufficient oil under all operating conditions, the Hydra-Matic (like all other fully automatic transmissions) requires two separate pumps: (1) a front pump driven by the engine which supplies the transmission any time the engine is running, (2) a rear pump driven by the transmission output shaft (and propeller shaft) which supplies oil only when the car is moving as during a dead-engine push start. Thus the two pumps supplement each other.

Originally both the front and rear Hydra-Matic oil pumps were of the simple external-twin-gear type illustrated in Figure 8 and driven through spiral gearing from their respective transmission or propeller shafts.

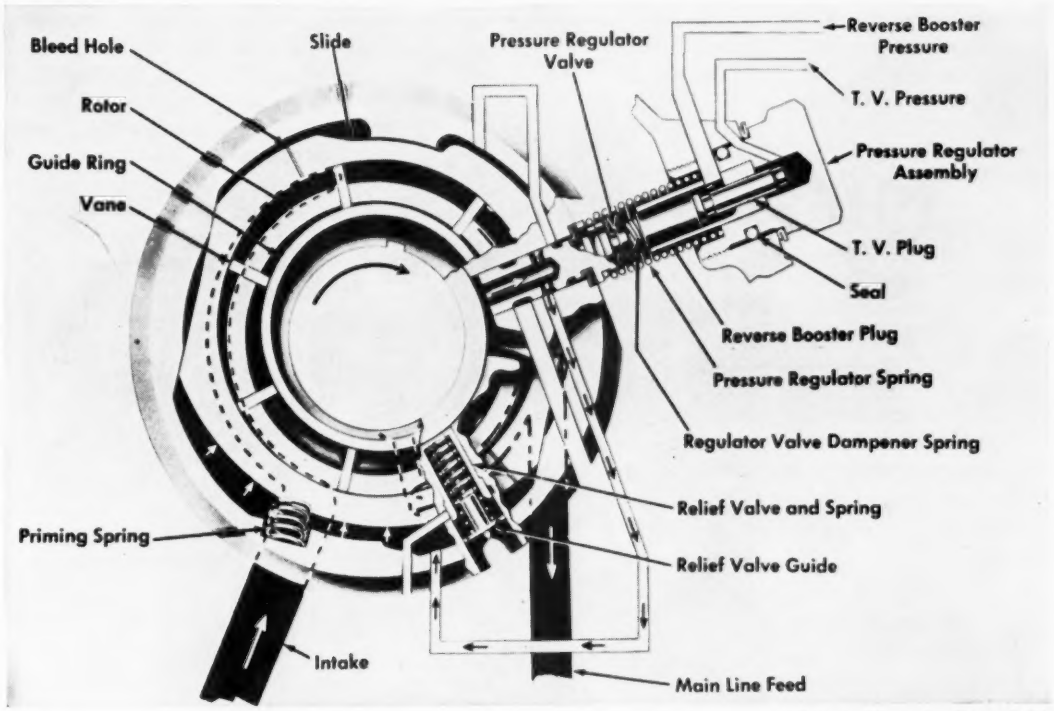
In 1946 the front pump was changed to a quieter and more capacious internal gear type illustrated on the right of Figure 9. One large advantage of the internal gear type was that it was coaxial with and could surround its own drive shaft which eliminated a pair of spiral gears, and considerably simplified both the pump installation and connecting plumbing.

After the car has attained normal driving speeds, the rear oil pump has adequate capacity for all transmission requirements. At this time the ordinary fixed-displacement type front pump is not only superfluous but wasteful since it continues to absorb engine power by pumping unwanted oil and uselessly discharging it through a relief valve back into the oil pan. In the continuous quest for



Pontiac Motor Car Div., GMC

Figure 9 — Oil Pump, internal gear type with hydraulic governor.



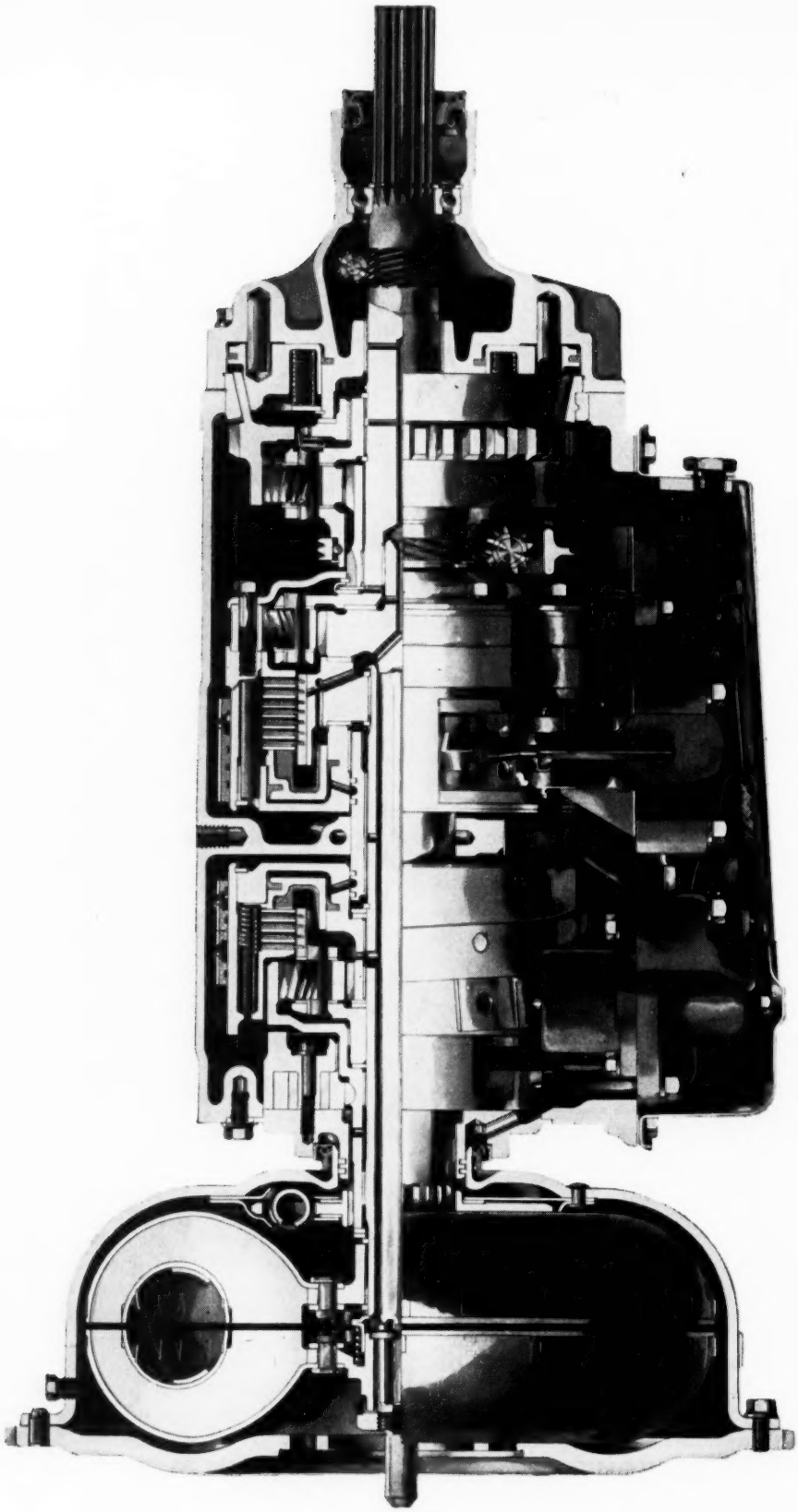
Pontiac Motor Car Div., GMC

Figure 10 — Oil Pump, variable displacement vane type.

even further improvements, the front pump came under study as offering another potential addition to the already high efficiency of the Hydra-Matic. This problem was ingeniously solved in the 1952 and subsequent Hydra-Matics by the unique variable displacement front pump illustrated in Figure 10. A casual glance would mislead the reader into assuming that this was just another fixed displacement pump of the vane type. More careful examination, however, will show that the driving rotor with its six vanes actually rotates within the cylindrical housing furnished by a movable slide, and that the position of this slide determines the displacement of the pump, the first such pump among all transmissions. For example, when the slide is in its uppermost position (as illustrated in Figure 10) with its bore at maximum eccentricity to the vane rotor, the pump operates at its maximum capacity. If the slide is moved downward to its central position so that there is no eccentricity, the vanes merely rotate without causing any displacement, or in other words the pump does not pump. When the slide is moved even further downward it becomes a relief valve for excessive output by the *rear* pump. When not running, the slide is kept in its upper maximum-capacity position by the priming springs so that it will immediately build up oil pressure when started. During operation the position of the slide and the pump's capacity is determined by oil discharge pressure acting on the balanced stepped piston of the "pressure regulator valve" which in turn admits oil to the upper and lower ends of the slide to position it by hydraulic methods. The pressure regulator valve itself is subjected to three oil pressures from itself and other devices in the transmission's control system, consequently it integrates or balances these pressures to determine and control its own most desirable main line discharge pressure.

Reverse Planetary Gear Set

Reverting for the moment to Figures 1 and 2, it will be recalled that reverse action is obtained in the second or central planetary by driving its sun gear, restraining its planet carrier and obtaining output in reverse from its internal gear. Again from Figure 2 it will be noted that the internal gear of the second planetary drives the sun gear of the third or reverse planetary gear set and that the latter's planet carrier is permanently fixed to the transmission's output shaft. To transmit and increase the reverse torque from the second planetary it is then only necessary to hold the internal gear of the third planetary. In the earliest Hydra-Matics this was simply accomplished wholly mechanically by inserting the "reverse planetary dog" between any two of the coarse teeth on the exterior of the reverse planetary's internal gear. Subsequent to 1946 and to foil any thoughtless driver who might attempt to shift into reverse while the car was roll-



Detroit Transmission Div., GMC

Figure 11 — 1951 Hydra-Matic, Cross Section.

ing forward, the transmission manufacturer installed a "reverse blocker piston" which was hydraulically operated by oil pressure from the rear pump and which prevented such violent abuse of the reverse planetary.

Before passing on to later developments, it is of interest to note that even the earliest Hydra-Matics anticipated all others by having a built-in "Park" arrangement, though it was not until some years later that competitive pressure caused this faculty to be plainly marked on the driver's selector lever quadrant. Assisted by Figure 2 the reader will recall that the servo of the second or central planetary is applied by means of a strong internal spring and therefore firmly and automatically holds the second planetary internal gear with the attached sun gear of the reverse planetary whenever there is no transmission oil pressure, i.e. when the engine is not running. Thus the reverse planetary is firmly locked together and the car is "Parked" by merely stopping the car, turning off the engine and leisurely placing the driver's selector lever in its "R" (reverse) position.

Primarily to improve "rocking ability" (shifting alternately from forward to reverse so as to "rock" out of deep mud or snow), the 1951 and subsequent Hydra-Matics were fitted with the entirely new cone clutch type reverse planetary illustrated in Figure 11. It will be noted that a cone-shaped rearward extension of the reverse planetary internal gear is contained between an external stationary sleeve and an internal stationary annular hydraulic piston, both of the latter equipped with conical friction surfaces to match those of the extension on the internal gear. Oil pressure applied to the exterior (right hand) side of the piston forces it and the reverse planetary extension into frictional but firm contact with the stationary outer cone, thus stopping the former and holding all three. Upon release of oil pressure, six helical springs force the piston to the right and disengage the clutch. Since the reverse planetary clutch is engaged hydraulically, it can not hold during parking, consequently, for this purpose, the reverse planetary internal gear continues to be provided with notched teeth to engage with a manually-shifted parking dog. In the latest Hydra-Matics where the Park position is shown on the quadrant, the engine may be started in this position (as on a hill) without the necessity of using the brakes to hold the car. A comparison of Figures 1 and 11 will reveal many other improvements that were made during the ten years between them and in spite of the intervening World War II.

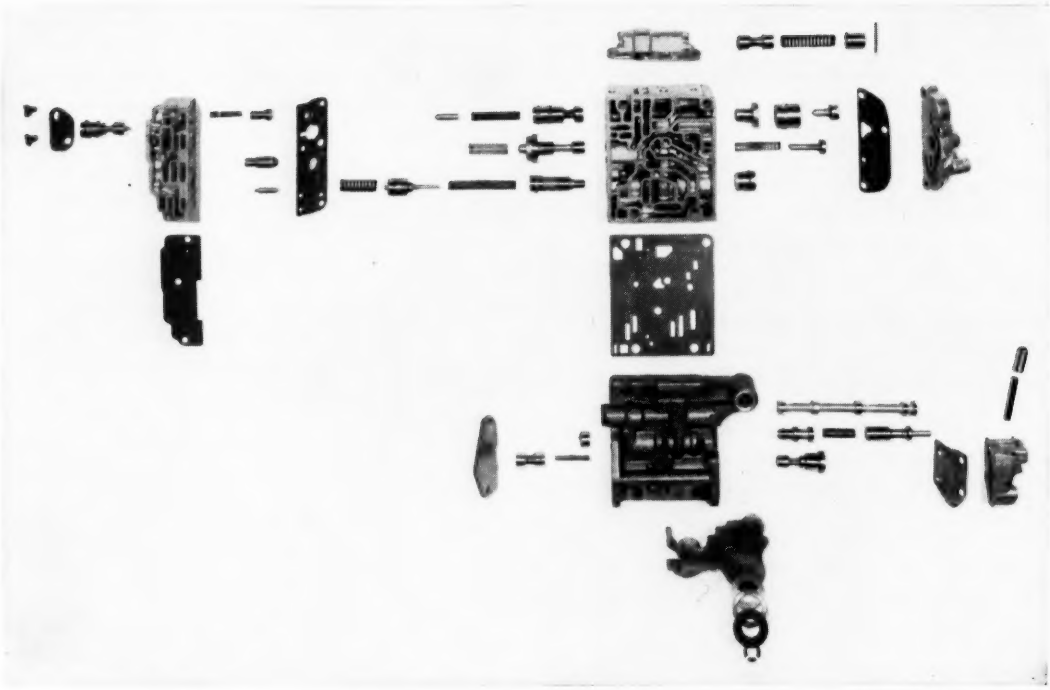
Hydra-Matic Control System

There are only three primary controls: (1) the driver's selector lever with its indicator quadrant, the former being connected to the transmission's "manual valve"; (2) the foot throttle pedal which is linked both to the carburetor throttle and to the transmission's throttle valve and (3) the speed of the car as indicated by rear transmission oil pump pressure and modified by a rotating centrifugal hydraulic governor.

The original quadrant had only the following four choices reading from the driver's left: "N" (Neutral), "Dr" (Drive), "LO" (Low Range) and "R" (Reverse). In later models the Dr position was split into two: (1) a normal cruising or country-drive position which employed all four forward gear ratios and (2) a high performance or city position in which the transmission used third gear as its "high" gear unless very high road speeds were attempted and the transmission then saved the engine and overruled the thoughtless driver by permitting itself to shift into fourth. The LO (Low) selector position merely restricts the transmission to its first and second gears at normal engine speeds, but allows an upshift at excessive engine speeds to preserve the engine.

By positioning his foot throttle, the driver specifies how fast he wishes to travel or how rapidly he wants to accelerate. For example, at a very moderate throttle opening the Hydra-Matic may be able to start and complete all three forward upshifts into high gear before the car reaches a speed of 25 mph. but as throttle opening is increased, the gear changes are correspondingly postponed or stretched out to give maximum performance so that at full throttle the last (three to four) shift may not occur until a car speed in excess of 70 mph. is attained. Within desirable car speed range if the driver "puts it to the floor" and passes through a recognizable slight resistance caused by a "detent", he will overrule the transmission's control system and cause it to execute a "forced downshift" into the next lower gear.

Excepting only the reverse dog or parking pawl operations, all Hydra-Matic gearshifts are determined and executed in proper sequence and at the proper time by its exceedingly clever but necessarily complex hydraulic control system. As an illustration of both the complexity and the importance of precise timing, consider only the first planetaries' share in a shift from second to third gears as shown in Figure 2 and Table I. To accomplish this shift the control system must change the first planetary gear from Direct to Reduction by applying its band and releasing its clutch. Remembering that the internal gear of this planetary is always engine-driven, if the band is applied much *before* the clutch is released, the whole planetary is not only locked up within itself, but also held rigidly to the stationary transmission case. Result: the engine would be violently decelerated and stalled. Now if the band were applied much *after*



Oldsmobile Div., GMC

Figure 12 — Control Body and Valves.

the clutch is released, the planetary gear set would be temporarily in neutral, and the unloaded engine would accelerate and try to run away. Neither of these conditions would be desirable: on the contrary we would like the band to be applied simultaneously or at such slight time ahead of the clutch release and with such firmness that the engine would mildly decelerate and quickly but smoothly re-establish synchronism.

The bulk but by no means all of the Hydra-Matic's beautifully finished control valves, accurate orifices and calibrated springs are contained in the complexly-passaged "control body" shown disassembled in Figure 12. Since the control system is one of the several means of fitting the highly adaptable Hydra-Matic to different vehicles, there are hundreds of variations and no attempt will be made to describe any one. The main purpose of Figure 12 is therefore to arouse the respect of the reader for this fine mechanism and to emphasize that no one but a carefully trained specialist on the Hydra-Matic should ever attempt to readjust or disassemble it.

THE 1956 HYDRA-MATIC

The 1956 Hydra-Matic illustrated in Figures 13 and 14 has been completely redesigned and is an entirely new transmission which contains not only the tried-and-true principles established in sixteen years and over 7,000,000 distinguished predecessors, but also a number of new principles or new applications of old principles not hitherto used in the Hydra-Matic.

Controlled Fluid Coupling

Even the most casual comparison of Figure 13 with Figure 11 would reveal that the 1956 Hydra-Matic employs a second though smaller fluid coupling. Unlike the big brother (which is always filled with oil under pressure) the new small coupling is of the controlled type, that is its torque-transmitting property can be brought in fully or canceled entirely by filling or draining its oil. The first planetary's gearing has also been moved forward into the large fluid coupling housing where it is always submerged in oil and gives even quieter operation. But further examination of Figure 14 will show that the first planetary gear now has no multi-disc clutch nor for that matter any control band. The controlled coupling replaces the multi-disc clutch and provides an unbelievably smooth method for changing the first planetary between its reduction and direct drive operations. The sprag clutch replaces the old brake band with its hydraulic servo. However, to completely understand the new first planetary we must digress for a moment to examine the principle and useage of a sprag type one-way clutch, a mechanism not previously used in any Hydra-Matic.

Figure 15 schematically illustrates a portion of such a clutch which consists of smooth cylindrical inner and outer races, as many "sprags" as can

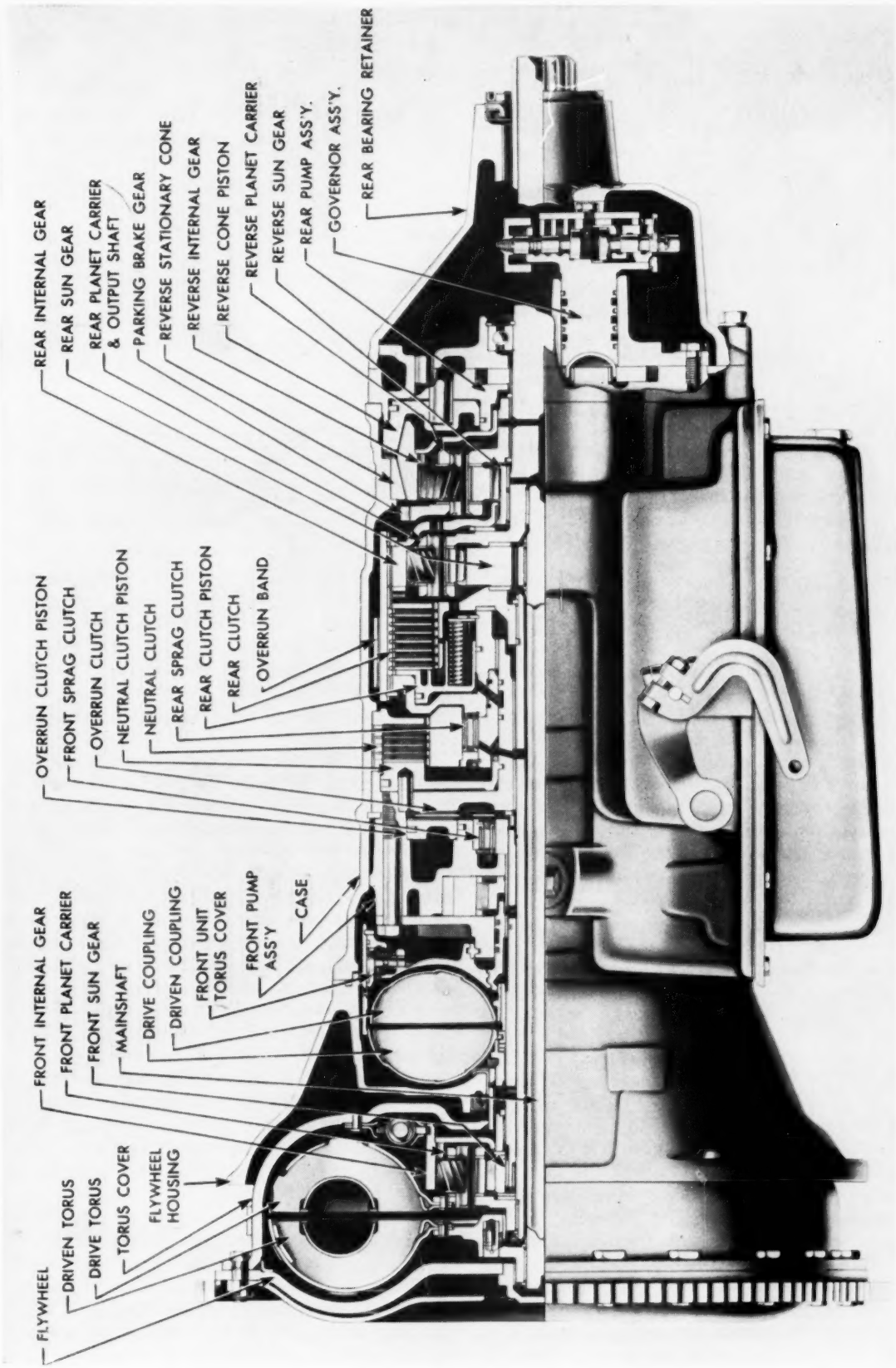
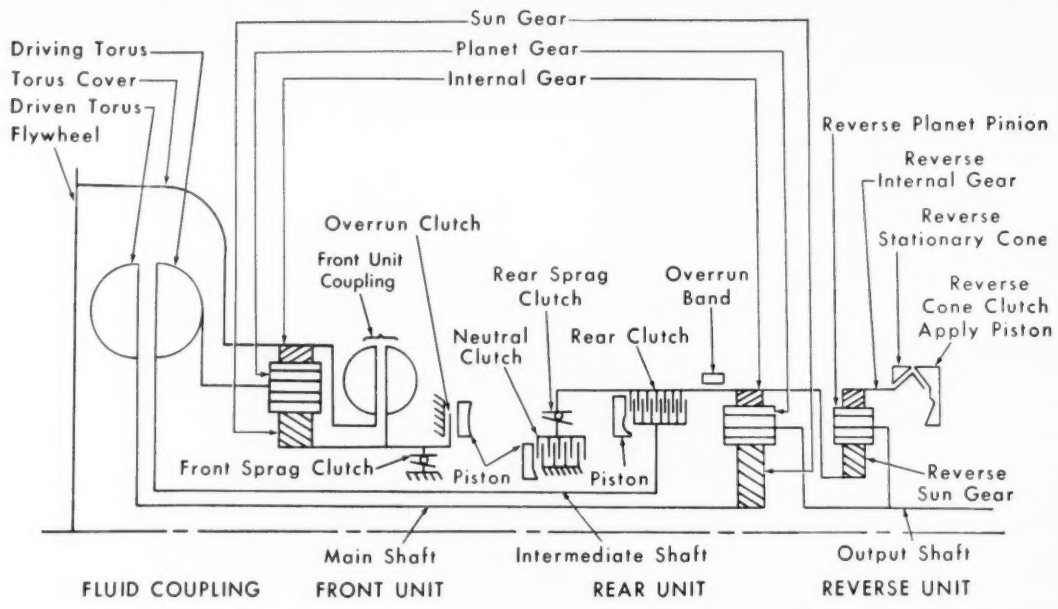


Figure 13 — 1956 Hydra-Matic, Cross Section.

Detroit Transmission Div., G.M.C.



Cadillac Motor Car Div., GMC

Figure 14 — 1956 Hydra-Matic — Schematic.

be placed between them, and a formed "teasing" spring which tends to rotate each sprag around its own axis in a clockwise direction. Looking again at Figure 15 it will be seen that if the outer race is stationary, the inner race can be rotated freely in a clockwise direction since the sprags slide easily along the races. However if *counter*clockwise rotation of the inner race is attempted, each sprag immediately and automatically wedges between its portion of the inner and outer races, and thereby prevents counterclockwise rotation. In effect, the sprag type one-way clutch is like the common ratchet, though the sprag clutch has no teeth, has far greater capacity and ruggedness and is completely quiet.

First Planetary Gear Set ("Front Unit")

Now let's look back at Figures 3 and 14 by which the ingenious application of a sprag one-way clutch may be examined and appreciated. In the 1956 Hydra-Matic as in its predecessors, the internal gear of the first planetary (or front unit) is directly connected to the engine and is therefore always driven in a clockwise direction along with the connected drive torus of the small front unit coupling. The output of the first planetary is through its planet carrier. Now assume that the front unit coupling contains no oil and is therefore inactive. When the first planetary is in reduction, the sun gear is stationary and must furnish reaction to the planets. Under this condition the sun gear tends to rotate counterclockwise but is prevented and held stationary by the just-described "front sprag clutch" which takes hold smoothly and automatically as soon as reaction is required and without the necessity for any other timing or governing mechanism. The planets must therefore walk around the sun gear and carry their carrier in the same direction but lower speed than the internal gear. *The first planetary* (or "front unit") *is therefore automatically in reduction whenever the front unit coupling is empty.*

Now let's fill the front unit coupling with oil and determine its effect. Since the drive torus of this small coupling is connected to the front unit internal gear and the driven torus to the sun gear, the internal and sun gears are now hydraulically connected, both rotate clockwise at essentially the same speed, and carry the planet carrier along with them at the same speed. Since the front sprag clutch permits *clockwise* rotation of the sun gear, it releases automatically and there is no interference. And since all assemblies of the front planetary unit are now rotating in the same direction and at the same speed, the unit is now in direct drive.

To sum up the foregoing, the first planetary of the 1956 Hydra-Matic is simply controlled by merely emptying or filling its fluid coupling. With an empty coupling, the planetary unit is in reduction; with a full coupling the unit is in direct drive. It should be noted that this unit is now capable of only the reduction and direct drive phases of planetary gear operation, i.e., it is always active and has no neutral phase. From the smoothness standpoint there is no necessity whatsoever for any careful timing, since the sprag clutch will operate automatically as soon as the unit coupling

is adequately filled to cause the desired shift in the planetary. The shift is so smooth that only the slight change in engine speed is indicative that it has occurred.

Second Planetary Gear Set ("Rear Unit")

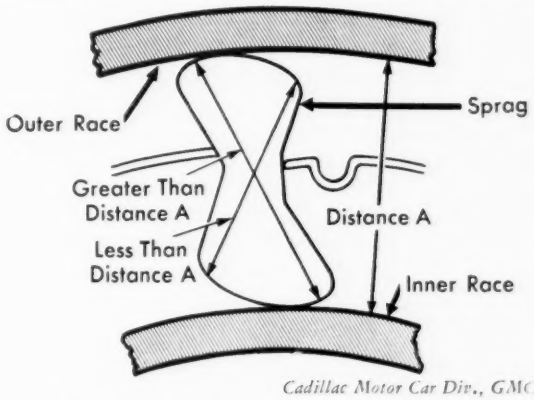
The four basic parts of this planetary are (1) the planetary gear set itself, (2) the rear clutch, (3) the rear sprag clutch and (4) the neutral clutch. Reference to Figures 3 and 14 will show that the sun gear of this unit receives torque through the mainshaft from the driven torus of the large coupling. The rear clutch hub similarly receives torque through the intermediate shaft from the driving torus. The internal gear is splined to the rear clutch drum which in turn is connected to the rear sprag clutch inner race. The outer race of the sprag clutch is also the neutral clutch hub. The driven plates of the neutral clutch are attached to the transmission case and are therefore always stationary. Here then we have a variation of the sprag type one-way clutch in which the clutch acts in its normal one-way capacity only if its outer race is held stationary by engaging the neutral clutch. Conversely if the neutral clutch is *not* engaged, this "one-way clutch" belies its name since it is then "free" or ineffective and permits rotation in either direction.

Like its predecessors, the second planetary may also operate in any of four phases which are briefly outlined as follows:

1. *Reduction* — The Neutral clutch is applied and the rear sprag clutch prevents any counterclockwise rotation of the internal gear. Rear clutch is released, consequently the only torque input is clockwise and into the sun gear (via the driven torus of the large coupling). The planets are driven counterclockwise around their own axes and by virtue of the stationary internal gear must carry the planet carrier clockwise at a reduced speed.
2. *Direct Drive* — The rear clutch is applied, thus permitting the driving torus of the large coupling to drive the internal gear clockwise. A piston-type fluid accumulator is used to modify the application and insure smoothness of this clutch. Similarly the driven torus continues to drive the sun gear clockwise. With both the internal and sun gears rotating in the same direction and at the same speed, the planet carrier is carried along between them at the same speed and the second planetary in effect is in direct drive.
3. *Neutral* — As in previous Hydra-Matics the planet carriers of both the second and third (reverse) planetaries are permanently connected to the transmission's output shaft. Likewise the internal gear of the second planetary and the sun gear of the third are also permanently connected together. When both the rear and neutral clutches are released, torque is transmitted from the driven torus of the large coupling to the second planetary's sun gear in a clockwise direction. The planets of the second planetary are rotated counterclockwise on their own axes and must drive their internal gear in a counterclockwise or reverse direction which is transmitted to the sun gear of the third or reverse planetary. Since the internal gear of the third planetary has not been restrained, the third unit planets merely rotate clockwise around their own axes and drive the internal gear idly clockwise without imposing any torque on the planet carrier and transmission output. The Neutral position is thus effected by combination of the second and third planetaries.
4. *Reverse* — From the foregoing paragraph it may be seen that when the second planetary is placed in neutral, a reversal of rotation with torque multiplication occurs which is transmitted to the sun gear of the third. To obtain reverse drive it is then only necessary to hold the internal gear of the third planetary which forces its planets to rotate clockwise on their own axes while walking counterclockwise around the internal gear and of course taking their carrier with them at decreased output speed. Additional torque multiplication therefore occurs in the third planetary. As in its immediate predecessors, the 1956 Hydra-Matic holds the third planetary internal gear by means of a hydraulically applied cone clutch.

Parking Position

Before leaving the third planetary the reader's attention is invited to the adjacent presence of a new "parking brake gear" which is attached to the third planetary gear carrier and therefore to the transmission's output and the car's propellor shaft. A stationary pawl is inserted into the teeth of this gear by purely mechanical linkage from the driver's selector lever. When the engine is started



Cadillac Motor Car Div., GMC

Figure 15 — Sprag type one-way clutch, schematic.

Drive Range	Speed	FRONT UNIT			REAR UNIT				REVERSE UNIT	
		Controlled Coupling	Front Sprag Clutch	Overrun Clutch	Neutral Clutch	Rear Spring Clutch	Rear Clutch	Overrun Band	Reverse cone Clutch	Parking Pawl
PARK		REDUCTION			NEUTRAL				IDLING	
		Empty	On	Off	Off	On	Off	Off	Off	On
NEUTRAL		REDUCTION			NEUTRAL				IDLING	
		Empty	On	Off	Off	On	Off	Off	Off	Off
DR 4	1	REDUCTION			REDUCTION				IDLING	
		Empty	On	Off	On	On	Off	Off	Off	Off
	2	DIRECT DRIVE			REDUCTION				IDLING	
		Full	Off	Off	On	On	Off	Off	Off	Off
	3	REDUCTION			DIRECT DRIVE				IDLING	
		Empty	On	Off	On	Off	On	Off	Off	Off
	4	DIRECT DRIVE			DIRECT DRIVE				IDLING	
		Full	Off	Off	On	Off	On	Off	Off	Off
DR 3	1	REDUCTION			REDUCTION				IDLING	
		Empty	On	On	On	On	Off	Off	Off	Off
	2	DIRECT DRIVE			REDUCTION				IDLING	
		Full	Off	Off	On	On	Off	Off	Off	Off
	3	REDUCTION			DIRECT DRIVE				IDLING	
		Empty	On	On	On	Off	On	Off	Off	Off
LO	1	REDUCTION			REDUCTION				IDLING	
		Empty	On	On	On	On	Off	On	Off	Off
	2	DIRECT DRIVE			REDUCTION				IDLING	
		Full	Off	Off	On	On	Off	On	Off	Off
REVERSE		REDUCTION			NEUTRAL				REDUCTION	
		Empty	On	On	Off	On	Off	Off	On	Off

Cadillac Motor Car Div., GMC

Figure 16 — 1956 Hydra-Matic Planetary and Controlled Coupling Useage.

with the transmission selector lever in Park position, the transmission itself is actually in Neutral as previously described.

Planetary Useage

With the single and unimportant exception that the first planetary is incapable of a neutral position, the three planetary gear sets of the 1956 Hydra-Matic collaborate exactly like their predecessors as shown in Table I to produce four forward gear ratios, one reverse, a neutral position and a wholly mechanical Park position. Figure 16 presents a detailed picture of the useage of the planetaries and subsidiary controls. The new hydraulic control system retaining all earlier safety features, is similar though somewhat simpler and less critical than its predecessors since precise timing of clutch and band applications is no longer required.

Overrun Clutch and Overrun Band

In Figures 13 and 14 the observant reader undoubtedly noticed these two mechanisms and may wonder why they have been ignored so far. The fact is that neither of them is active or applicable during normal driving where the engine is driving the car. But under a few planetary conditions and only when the car tends to drive or "overrun" the engine (as when decelerating or descending a hill with closed throttle) torque is reversed through the front and rear sprag one-way clutches, they are prevented from operating normally and unless otherwise prevented the car would tend to "free wheel". However and from their positions in Figure 14 it will be noted that application of the overrun clutch effectively locks up the front sprag clutch in the third gear range while the overrun band will give similar service for the rear sprag clutch in the manual low range, thus preventing free wheeling in these ranges. Both the overrun clutch and overrun band are applied hydraulically when required as indicated in Figure 16.

Lubrication

Even the most casual understanding of the passenger car Hydra-Matic should include the realization that the fluid used in it must be regarded as a highly essential special part that must perform all of the following important and often diverse functions, and all with very high ability:

1. A mild extreme pressure gear lubricant to protect heavily loaded helical and spiral gearing.
2. A torque fluid with non-foaming characteristics for fluid coupling operation.
3. A hydraulic fluid capable of permitting the Hydra-Matic to operate between minus 30 and plus 300°F.
4. A wet clutch and transmission band lubricant that facilitates the smooth and noiseless initial engagement of these mechanisms without permitting subsequent slippage.
5. A lubricant with such high oxidation resistance that it can withstand exposure to atmospheric oxygen for 25,000 miles at high temperatures and abundant catalysis without forming sludge or varnish that would prevent proper operation of the Hydra-Matic's many control valves.
6. A rust preventive and anti-corrosion lubricant which will not adversely affect any of the many metals, rubber seals, gaskets, adhesives, clutch facings and band liners used in the Hydra-Matic.

Since nothing with such highly special characteristics was initially available, two refiners developed fluids which General Motors used for the initial factory fill of new transmissions and also marketed under a GM part number for distribution only through its own car service outlets. As the popularity and production of the Hydra-Matic increased, and other transmissions requiring a similar standardized fluid were introduced, General Motors issued a fluid specification and arranged for Armour Research Institute to conduct most of the requisite tests so that additional refiners could also develop suitable approved fluids and distribute them through their own oil company service stations. All fluids developed and approved under these arrangements are assigned an AQ-ATF ("Armour-Qualified Automatic Transmission Fluid") number larger than 100 which must be stamped on quart can tops or stenciled on larger containers. Any Hydra-Matic owner who uses anything but an approved AQ-ATF fluid in his fine transmission is not only inviting expensive trouble but will get scant sympathy from the car manufacturer. Exclusive use of an approved AQ-ATF and replacement of it each 25,000 miles is by far the cheapest assurance of obtaining the long satisfactory service that so many millions of Hydra-Matics have demonstrated.

THE TWIN HYDRA-MATIC HEAVY TRUCK TRANSMISSION

The Problem

A trucker like most people is in business to make a profit (and he can stay in business only as long as a profit exists).

Profit is simply the positive difference between income and expense. Income is pretty well limited by competition and prescribed freight rates. Profit therefore depends most largely on achieving minimum expense. In other words, a trucker is in the business of moving the most freight *quickly, safely* and *economically;* if he fails seriously in any of these three, he's no longer in business.

Quickly

In proportion to the weights they move, truck engines have always been much smaller than passenger car engines. Though mention of the fact makes any truckman shudder, trucks are definitely underpowered by comparison, and as profit-making vehicles they probably always will be. But their much lesser agility, particularly on hills, makes it difficult to maintain schedules, either through city traffic or rolling country. Nevertheless only a good average speed maintained hour after hour will cost the least and pay the largest dividends. The answer is an automatic transmission that at all times accurately balances the engine's ability against the requirements of load, road and schedule.

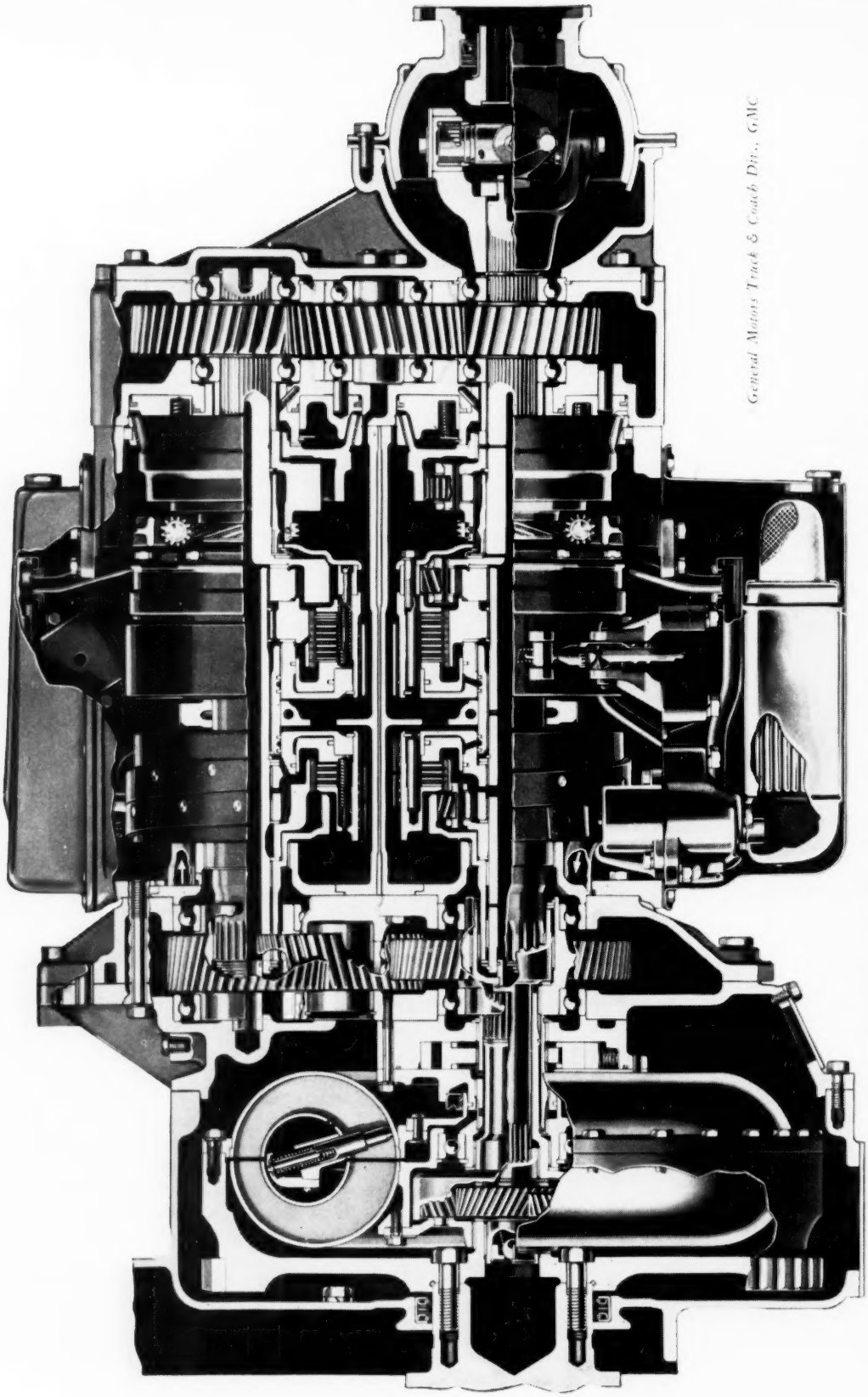
Safely

"Letting her roll" down hills to try to make up time that was lost in lugging up them is fraught with peril for all. And there's nothing more lethal than a truck out of gear on a down-grade with a dead engine. Double clutching is out and it's frequently impossible otherwise to get back into gear. Even the best of brakes will quickly burn or fade to uselessness in such an emergency. The engine must always be useable either for power or as a brake; the solution is a transmission that is never out of gear.

The driver's attention and energies should not be diverted or wasted in routine manual gear shifting, but concerned with watching traffic and the road. Lack of experience or error in selecting the proper gear can lead to serious consequences. A crippled truck alongside the road is expensive, but one involved in an accident can be prohibitive. The solution to this requirement is a transmission that automatically selects and shifts into the best ratio without any driver attention.

Economically

Fuel cost, always a major expense, is steadily increasing, almost wholly because of added federal, state and local taxes. The trucker should be most concerned with obtaining the most ton miles per



General Motors Truck & Coach Div., GMC

Figure 17 — Twin Hydra-Matic Truck Transmission (Syncromesh reduction unit not shown)

dollar, but under these circumstances he can only try for the highest ton miles per gallon, or the most efficient utilization of his fuel. Heavy duty engines are most efficient — use the least fuel per horsepower — within a relatively narrow speed range. Furthermore, operation much below or above this speed range will shorten engine life and give increased maintenance cost. Therefore, for least overall cost, and regardless of load, schedule and road gradient, the engine should always operate within its proper speed limits. Some drivers are unwilling or unable to accomplish this with a standard transmission and none should be expected to. The solution again is a fully automatic transmission having an adequate number of gear ratios without excessive overlap.

Tabulating these several requirements of the desired truck super-transmission we have the following:

Requirement	*Reason*
1. Geared transmission	Best economy and engine braking
2. Automatic shifts	Best engine and vehicle performance, safety
3. Always in gear	Safety, low maintenance
4. Adequate number of ratios	Best engine and vehicle performance
5. Close control of engine speed	Best economy, lowest maintenance
6. Proven dependability	Lowest operating and maintenance costs
7. Minimum first cost	Commensurate with the above

These seven requirements are admittedly severe and until recently no truck transmission could even approach them. But the existing passenger car Hydra-Matic could certainly fulfill all but the fourth and fifth, therefore some adaptation of it offered by far the most promise. Such an adaptation has been most ingeniously accomplished and was introduced in 1954 to long distance truckers as the Twin Hydra-Matic Drive. The Twin Hydra-Matic with a two or three speed reduction unit is available in a series of truck models from 42,000 GVW to 70,000 lbs. GCW.

From its name and as illustrated in Figure 17 the reader will recognize the major elements of this truck transmission as two identical Hydra-Matic planetary gear sets fastened top-to-top and geared together in tandem or parallel at both their input and output ends to form a working team. Not so evident is the fact that the large helical output gears of the two Hydra-Matics are of different size so that they operate at slightly different speeds. In gasoline-engined models the upper Hydra-Matic runs slightly faster; in diesel-engined units, slightly slower. Since each has its own governor and control system, the two Hydra-Matics shift independently of each other, however their difference in output speeds causes them to "take turns", i.e., during acceleration they will make alternate shifts for a total of seven with combined output ratios (for diesel-engined trucks) ranging from 2.90 (both units in first gear) to 0.71 (both units in fourth).

To obtain additional speed reduction and increased torque multiplication a manually-shifted two or three speed synchromesh reduction unit is always fitted to the output of the Twin Hydra-Matic. Since this reduction unit is quite similar to a conventional manually-shifted three-speed transmission, it has not been illustrated.

Unlike the Twin Hydra-Matic which can shift under full engine torque, any manually-shifted geared transmission must be relieved of torque before its gears can be moved. In this one, the shift lever is linked to an electrical over-rule switch which operates a solenoid connected to each Hydra-Matic manual valve and thereby places both of the Hydra-Matic units in neutral during the short period of manual gear shift. With capacity load, the driver will start in either the "creeper" or "low" range of the reduction unit and manually shift into direct. Since the Twin Hydra-Matic has very adequate ratio range within itself, a minimum of shifting in the reduction unit is necessary thereafter. The following Table II illustrates the wide range of total (engine-to-wheel-axle) reduction ratios that are obtainable and also the severe grades that can be negotiated.

Since the output shafts of the two Hydra-Matic units are solidly geared together and since each changes ratios independently, special arrangement must be made to automatically and equably distribute engine torque between them. This is cleverly accomplished by using a special extra planetary gear set (shown to the left of the fluid coupling in Figure 17) as a differential. The driven torus of the fluid coupling is attached to and drives the planet carrier which divides its torque between the internal and sun gears. The sun gear drives the lower of the Hydra-Matic units clockwise through the innermost connecting shaft. The internal gear drives the large helical gear just to the left of the lower Hydra-Matic and through it to the slightly larger and wider helical drive gear of the upper unit.

It will be noted that the single fluid coupling which drives both Hydra-Matics is not only considerably larger than the passenger car type (17 inch, to handle the greater engine torque) but that the driving torus contains forty unusual spring

TABLE II

Twin Hydra-Matic Reduction Ratios and Gradeability (with GM 4-71 diesel 3-speed syncromesh reduction unit, 60,000 GCW truck, 7.45 rear axle ratio).

Gear Positions		Total Reduction	% Grade at Max. Engine Torque, 60,000 lbs. GCW
Hydra-Matic	Red. Unit		
1st	Creeper	83.61	24.4
2nd	"	67.46	19.5
3rd	"	53.62	15.2
4th	"	41.75	11.7
5th	"	31.75	8.7
6th	"	25.66	6.8
7th	"	20.47	5.2
1st	Low	43.30	12.1
2nd	"	34.94	9.6
3rd	"	27.68	7.4
4th	"	21.66	5.6
5th	"	16.44	4.0
6th	"	13.24	3.0
7th	"	10.54	2.2
1st	Direct	21.65	5.6
2nd	"	17.47	4.3
3rd	"	13.84	3.2
4th	"	10.83	2.3
5th	"	8.22	1.5
6th	"	6.62	1.0
7th	"	5.27	.6

Courtesy General Motors Truck & Coach Div., GMC

loaded plungers called "spoilers" that perform an interesting function. It has been previously explained that at engine idle speed the fluid coupling of the passenger car Hydra-Matic will not transmit enough torque that even as multiplied by the Hydra-Matic's first (low) ratio and differential gearing, will be sufficient to move the car and cause it to "creep". This is definitely not true with the Twin Hydra-Matic both because of the large engine and also the much greater combined torque multiplication that must occur in transmission and differential, consequently some additional method is required to prevent creep. The spoilers accomplish this by spoiling orderly fluid flow and thereby decreasing the torque transmittal capacity of the fluid coupling at engine idle speeds. As engine speed is increased slightly above 700 RPM centrifugal force causes these spoilers to move outward against their spring pressures and at 900 RPM they are fully extended to permit orderly torque-transmitting fluid flow in the coupling to be re-established.

Controls

The Twin Hydra-Matic selector lever mounted on the steering column has four positions, namely: "Neutral", "Drive", "Hold" and "Reverse". "Neutral and Reverse" are self-explanatory. "Drive" position permits the Twin Hydra-Matic to shift throughout its normal sequence either up or down depending upon the demands of driver, vehicle, load and terrain. "Hold" position has two functions:

1. It prevents *upshifting* beyond the gear in which the Twin Hydra-Matic is operating at the time the selector lever is moved to the Hold position This is ideal when using the engine as a brake. A safety and engine-saving feature provided in the "Hold" position permits the Twin Hydra-Matic to upshift if for any reason the engine exceeds its maximum governed speed by 300 RPM.
2. In the "Hold" position, however, *downshifts* will occur as demanded by the vehicle. It permits downshifts in all gears to occur at a greater vehicle speed than they would normally occur in the "Drive" position. It is particularly advantageous when approaching an incline and vehicle speed is still relatively high to move the selector lever to Hold position since this causes all downshifts to occur at maximum vehicle speeds which in turn permits the engine to operate at higher RPM with maximum horsepower and efficiency.

Both of the Hydra-Matic units retain their individual rear oil pumps, governors and control bodies and both of the latter are linked to the drivers foot throttle, consequently the fully automatic features of their control systems operate much like that in a passenger car.

Lubrication

The two Hydra-Matic units with their fluid coupling have a common (but larger) front pump of the variable output type, and a common oil sump containing a total of 23 quarts. To keep oil temperature within reasonable limits, an oil-to-water heat exchanger shown in the oil pan of Figure 17 is provided.

Until very recently, the manufacturer has recommended exclusive use of an approved AQ-ATF automatic transmission fluid in the Twin Hydra-Matic with drain and replacement each 15,000 miles. However the manufacturers' latest instructions which are applicable to all existing and new Twin Hydra-Matics call for the use of only certain designated factory-approved brands of MIL-L-2104A heavy duty engine oils of the same viscosity grade as used in the engine with the following exceptions (1) the SAE 5W grade should not be used, (2) multi-viscosity grades such as 5W-20 or 10W-30 are not recommended, (3) In areas where the temperature stays at 0°F. or below for extended periods of time, Automatic Transmission Fluid Type A *should* be used.

The reduction unit containing 7 to 11 pints is similarly lubricated with the same type and SAE grade of heavy duty motor oil as the vehicle's engine.

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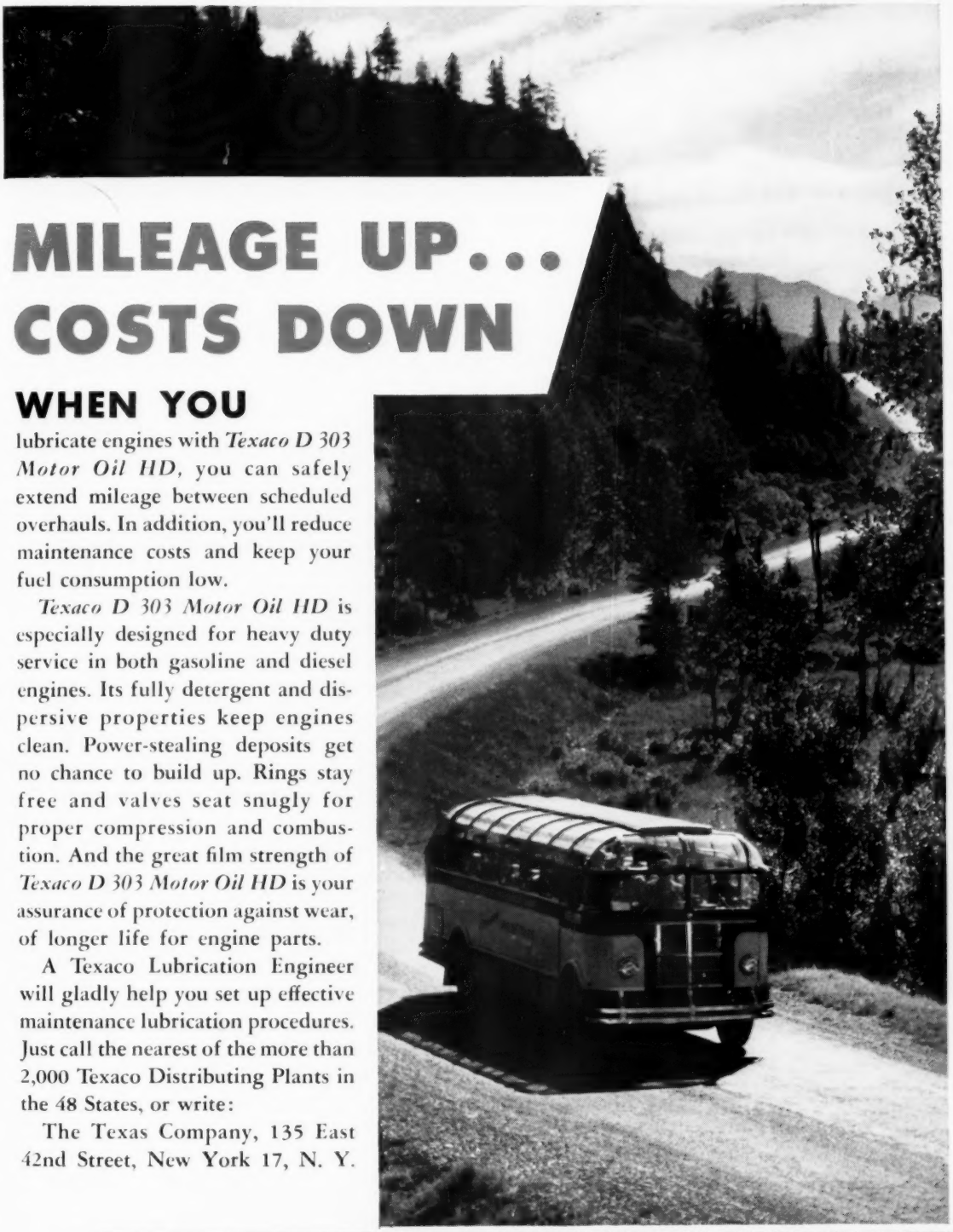

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In chassis bearings and on the fifth wheel, *Texaco Marfak* provides long-lasting protection that doesn't jolt out or squeeze out—adds greatly to the life of the chassis parts.

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